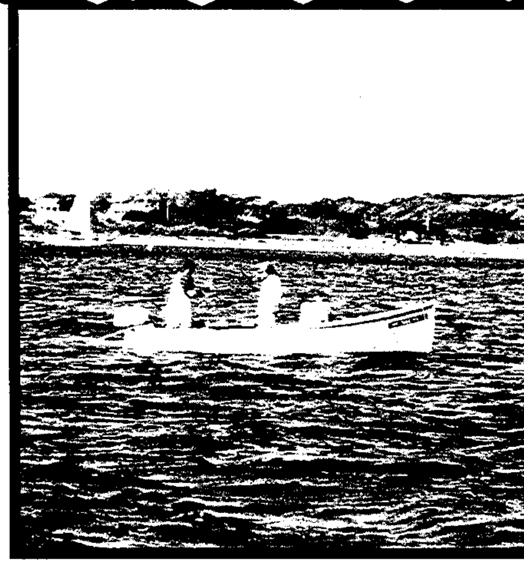
The State of the Bays

chapter II



CHAPTER II. THE STATE OF THE BAYS

Introduction

This chapter identifies important natural resource and socioeconomic characteristics of the Massachusetts Bays region, and offers an assessment of the current status of the Bays ecosystem, focusing on the priority problems and risks to habitats, living resources, and human health. It includes discussions of the major physical and biological features of the Bays; the diverse habitats of the Bays, including the human habitat; toxic contamination of the Bays habitats and living resources; and pathogen contamination of the Bays' sustainable resources.

To characterize the pollution problems of the Massachusetts Bays and to develop management solutions, the MBP undertook a major research program. This program was conducted by a variety of academic institutions, agencies, and authorities. Included was an in-depth analysis of three diverse embayments: Plum Island Sound, Weymouth Fore River Estuary, and Wellfleet Harbor. The results of the MBP research program and related studies were incorporated into the CCMP planning process. In particular, the recommended actions described in Chapters IV and V reflect the technical data from the research and studies.

Major Natural Features of the Bays Region

Geography, Geology, and Water Movements

The Massachusetts Bays region, shown in Figure II-1, encompasses all of the coastal waters of Massachusetts Bay from the tip of Cape Cod to the New Hampshire border, an area of about 1,650 square miles with a shoreline of more than 800 miles. The Bays are located at the southern end of the Gulf of Maine, a large coastal sea characterized by relatively cool water and large tidal ranges. The land draining into Massachusetts and Cape Cod Bays covers more than 7,000 square miles. Half of this area is comprised of numerous watersheds within Massachusetts; the other half is the watershed of the Merrimack River in New Hampshire.

The Bays region has a diverse geological history. Its shoreline includes beaches comprised of sand and gravel deposited by the glaciers, as well as rocky shores with exposed preglacial bedrock. The underwater topography of the Bays is a patchwork of mud, sand, gravel, and boulders (Knebel *et al.*, 1991). In places, these different types of ocean bottom occur as a mosaic within a relatively small area, particularly where fine sediments are constantly being reworked by physical and biological forces. This geologic diversity explains to a large extent the distribution pattern of pollutants. Areas with muddy bottoms tend to be more prone to pollutant deposition, as their relatively sluggish water movement facilitates the settling of fine particles and attached pollutants. In contrast, erosional areas are places where relatively rapid water movement tends to scour the bottom free of fine sediments, leaving behind relatively clean coarse grained particles and rocks.

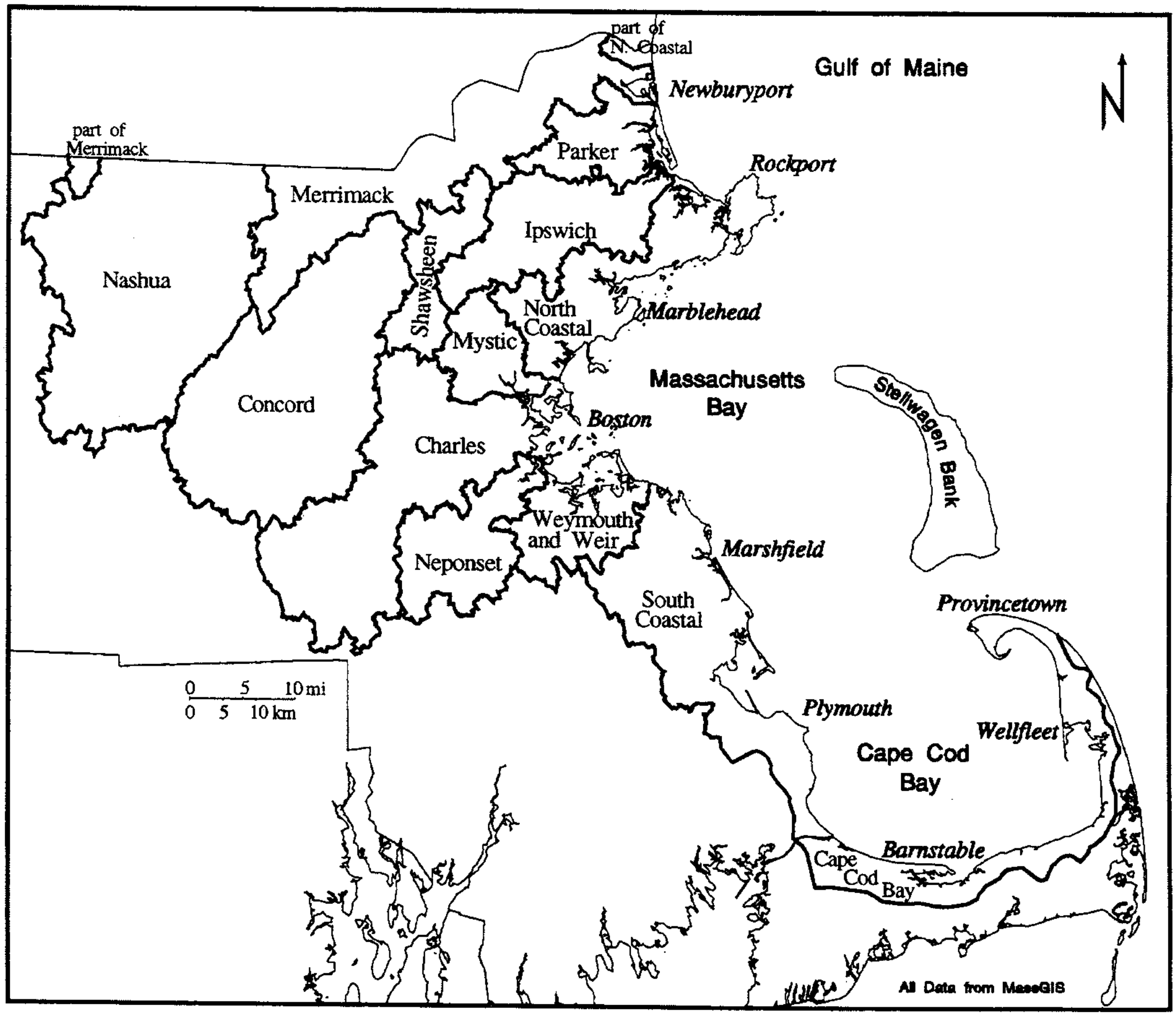
The MBP provided the funding for the first integrated study of the physical oceanography of the Massachusetts Bays (Geyer *et al.*, 1992). A key step in developing management solutions for the health of the Bays is understanding how pollutants move and are deposited throughout the region. Further, understanding the Bays' currents is essential in predicting how human activities (such as the major sewage outfall under construction in Massachusetts Bay) are likely to impact the marine environment.

In general, the Bays are strongly influenced by the southward flowing coastal current of the Gulf of Maine. This current, combined with the large flow of water from the Merrimack River, enters northern Massachusetts Bay between Stellwagen Bank and Cape Ann. The strength of this current varies with the season, running strongest during the spring when heavy spring rains and snowmelt result in high flows from the Merrimack River and the Maine rivers to the north. The water then flows from Massachusetts Bay into Cape Cod Bay, exiting the system around Provincetown. Water also enters Massachusetts Bays across Stellwagen Bank under the influence of strong tides. It should be understood that the overall counterclockwise circulation pattern in the Bays is a yearly average. This pattern may vary seasonally and even be reversed on any given day (Geyer *et al.*, 1992).

The residence time of water in different parts of the Bays varies from as little as a few days (Boston Harbor and other smaller embayments) to 20 - 45 days (Massachusetts Bays) to over six months (Stellwagen Basin). Particles are flushed more rapidly out of Massachusetts Bay than either Cape Cod Bay or Stellwagen Basin.

Compared to other east coast estuaries, the Massachusetts Bays do not contain a high volume of freshwater from rivers. Nonetheless, rivers may be important sources of selected pollutants to parts of the Bays since some pollutants, such as heavy metals and toxic organic compounds, are often adsorbed to particulate matter carried by rivers (Menzie-Cura, 1991; Menzie-Cura, 1995 a,b). Unlike

Figure II-1. The Massachusetts Bays and Their Watersheds



much of the rest of the Bays region, Cape Cod Bay receives almost all of its freshwater inputs from groundwater, since there are no large rivers discharging in that area.

The Massachusetts Bays undergo an annual cycle of stratification of water into distinct layers by depth. As the water warms in spring, it begins to stratify into a warmer, lighter surface layer, a narrow transitional layer called a pycnocline, and a colder, denser bottom layer. These layers become most pronounced in summer when there is little mixing between the surface and ocean bottom. Cooling temperatures and increasing winds during the fall season break down this stratification by mixing the water. The significance of this phenomenon for the biology of the Bays is that nutrients which support the growth of phytoplankton are used up in the surface waters during stratified periods and are eventually replenished when the waters mix again in the fall (Geyer *et al.*, 1992).

Biological Processes

The patterns of primary production by phytoplankton are related to the stratification cycle described above. As winter moves toward spring, the increased day length initiates a spring phytoplankton bloom, typically in February in Cape Cod Bay and in March in Massachusetts Bay. (Townsend *et al.*, 1990). Under the stratified conditions of summer, the phytoplankton, which must remain in the well lit surface waters, eventually deplete the nutrients, and their growth slows considerably. At the time of the fall turnover and breakdown of stratification, nutrients brought up from the bottom waters stimulate a fall bloom of phytoplankton. The particular species of phytoplankton present at any time also undergo seasonal changes, and can vary from year to year as well.

Productivity and chlorophyll estimates of Massachusetts and Cape Cod Bays are relatively low compared to other coastal regions. The annual productivity of Massachusetts Bay has been estimated at between 300-500 grams of carbon per square meter per year (Cura, 1991; Kelly, 1991; Kelly *et al.*, 1993). Chlorophyll concentrations, an indicator of the quantity of phytoplankton present, range from 1-4 mg per cubic meter per year in most of Massachusetts and Cape Cod Bays. Higher concentrations occur in some harbors and along eastern Cape Cod Bay (Kelly *et al.*, 1993).

Nutrients, particularly nitrogen, are required for the growth of phytoplankton, and hence provide a key to understanding patterns of productivity of the entire system. The largest single source of nitrogen to the Bays is water that enters the Bays from the Gulf of Maine (Cura and Freshman, 1992). The Massachusetts Water Resources Authority's (MWRA) treatment plant on Deer Island is the greatest single land-derived source of nitrogen to the Bays (Menzie-Cura *et al.*, 1991). About 20 percent of the local nitrogen loading to the Bays derives from the atmosphere (Zemba, 1996). In general, nitrogen concentrations in the Bays are highest in harbors and embayments, and then decrease with distance from shore. A study funded by the MBP is examining how the characteristics of Cape Cod Bay influence the physical and biological processes controlling the availability of nutrients, which can be a source of pollution when present in excess concentrations (Gardner *et al.*, in progress).

Cultural eutrophication, the excessive and deleterious growth of algae stimulated by artificially high nutrient inputs, has degraded a number of estuaries around the globe, including Chesapeake Bay and Long Island Sound. Symptoms of such eutrophication are not presently evident in Massachusetts and Cape Cod Bays. Most of the Bays waters are extremely well flushed, although the deep waters of Stellwagen Basin experience occasional depressions of dissolved oxygen in September and October (Geyer *et al.*, 1992). In general, eutrophication in the Bays system is considered a nearshore, localized condition that is limited to smaller embayments.

Most marine organisms depend directly or indirectly on the phytoplankton community. Zooplankton--most commonly microscopic animals related to shrimp and lobster or the larvae of fish and invertebrates--feed directly on phytoplankton as well as each other. The endangered right whale is attracted to Cape Cod Bay in late winter because of the high concentrations of copepods, the most abundant type of zooplankton in the Bays.

Blooms of nuisance algae are a major management concern. Red tide is caused by a dinoflagellate, *Alexandrium tamarense*. This organism produces a toxin that causes paralytic shellfish poisoning (PSP) in humans who ingest shellfish from waters where these organisms have bloomed. In recent years, red tides have been limited primarily to the Upper North Shore. One of the major concerns expressed by some about the new MWRA outfall (currently under construction) is that the nutrients it will release may stimulate blooms of the red tide organism transported south from Maine by the overall circulation patterns through the outfall area. Because the overall amount of nutrients will not change and the nutrients will be added below the zone where plankton can grow, most scientific evidence suggests it is unlikely that the new outfall will affect the frequency and extent of red tide blooms (US EPA, 1993). Nonetheless, it is a focus of monitoring efforts. (For more information on the MWRA project, please refer to the "Boston Harbor Project" discussion in Chapter IV.)

Other toxic algae occasionally identified in Massachusetts Bays include *Pseudonitzschia pungens*, which causes Amnesic Shellfish Poisoning (ASP) and *Dinophysis* sp., which induces diarrhetic shellfish poisoning. *Phaeocystis* (brown tide) is not toxic but is considered a nuisance algae because it fouls beaches, is odorous, clogs fishing nets, and can smother eelgrass and other marine life.

Living Resources Habitats of the Bays

Massachusetts and Cape Cod Bays are blessed with a diversity of estuarine and marine habitats. Protecting and enhancing these habitats is a priority of the Massachusetts Bays Program.

Salt Marshes

Salt marshes are intertidal grasslands and are among the world's most productive ecosystems. Currently, there are about 34,000 acres of salt marsh in Massachusetts and Cape Cod Bays (calculated by MBP from Mass GIS 1985 land use data). Almost half of this acreage is the wide expanse of marsh stretching from Plum Island Sound through Essex Bay on the Upper North Shore. Other large salt marshes are present in Scituate/Marshfield, Duxbury Bay, and Barnstable Harbor.

Over the years, many salt marshes in Massachusetts, particularly in the Metro Boston area, have been destroyed or degraded by filling for urban development. Adoption of the Massachusetts Wetlands Protection Act and accompanying Regulations in the 1970s has been instrumental in slowing this trend, as indicated by some recent estimates. These show only negligible losses since the 1970s in a relatively rural area (Plymouth County) and along the coast from Plum Island to Scituate. Another study, however, estimated an 8.8 percent loss of salt marsh over the same period in an urban marsh (Rumney Marsh in Saugus) that has been subject to encroachment and degradation.

Currently, the major threats to salt marshes are not the widespread filling witnessed in the past, but rather, small incremental losses and degradation due to commercial development, legal filling (e.g., public works projects), illegal filling, mosquito control, and pollution. Encroachment of salt marshes by the giant reed, *Phragmites australis*, has degraded numerous marshes where the natural flushing by seawater has become constrained. This aggressive and invasive plant can become the sole dominant species in a salt marsh, choking out other native flora and fauna that are dependent on the marsh environment. Sea level rise and the effects of development in the upland buffer zones adjacent to marshes present future challenges to the health of the Bays' salt marshes. MBP has provided funding to map potential coastal salt marsh restoration areas and to provide a socio-economic justification for restoration of these critical marshes (King *et al.*, in progress).

Tidal Flats

There are approximately 30,000-36,000 acres of tidal flats in Massachusetts and Cape Cod Bays. About 40 percent of this acreage occurs along Cape Cod Bay in Barnstable County. Duxbury and Plymouth Bays on the South Shore, and Ipswich Bay on the North Shore, also contain extensive tidal flats (Hankin *et al.*, 1985). In the past, tidal flats have been subjected to the same filling activities that have plagued salt marshes. In addition to outright loss, tidal flats are also prone to high levels of pollutants since they are areas of sediment accumulation. Tidal flats are especially important to human beings as they provide habitat for a number of commercially-important shellfish. They are also major feeding areas for migratory shorebirds, including several threatened and endangered species such as the piping plover and roseate tern.

Rocky Shores

Rocky shorelines constitute our most dramatic coastal scenery. They are most prevalent in the North Shore region extending from Nahant north through Cape Ann. Because they are well flushed by wave action, both the rocky intertidal shore and submerged kelp forests tend to be less affected by pollutants than other coastal habitats. Nonetheless, a recent study by Northeastern University indicated that even rocky shores can be degraded by severe pollution; in particular, oil spills constitute a potential threat (Witman, 1994).

Eelgrass Meadows

Eelgrass, *Zostera marina*, forms a rich underwater meadow that is a haven for a variety of fish and invertebrates (Buchsbaum, 1992). Because these meadows are subtidal (i.e., beneath the water surface), estimating their current acreage and health is a challenging proposition. Nevertheless, several initiatives have been launched in an effort to accomplish this.

Major threats to eelgrass are declines in water clarity, eutrophication, dredging, and boating activity (Orth and Moore, 1983; Costa, 1988 a,b). Eelgrass also is prone to natural population fluctuations resulting from intense coastal storms and a naturally occurring "wasting" disease.

Open Water

The nearshore open water of Massachusetts and Cape Cod Bays extends from the immediate shoreline to as deep as 100 meters in Stellwagen Basin. Much of this habitat is within the Commonwealth's Ocean Sanctuary Program or the Stellwagen Bank National Marine Sanctuary. A major management concern for this habitat is the protection of a number of endangered species, such as whales and sea turtles, that visit the area. Other concerns include fisheries management and maintenance of water quality and habitat integrity in the presence of a number of wastewater outfalls and dredge disposal sites.

Barrier Beaches and Coastal Dunes

Barrier beaches and coastal dunes encompass a complex of habitats, including intertidal areas, upper beach, wrack line, foredune, back dune, washouts, and interdunal swales and forests. These habitats are particularly important resting and feeding areas for migratory birds, and support a number of unique animals and plants, including various rare or endangered species, that can tolerate the desert-like conditions.

Barrier beaches are the coastal habitat used most intensively by people. As such, they present especially difficult management challenges. Conflicts commonly arise over balancing residential, commercial, and recreational interests with the preservation of natural values. In an effort to address this problem, the Commonwealth established a task force that brought diverse interest groups together to find areas of common ground and to reconcile differences. The result of their work is a guidance manual (*Guidelines for Barrier Beach Management in Massachusetts*, February 1994), which prescribes best management practices for a broad range of barrier beach activities and interests.

Estuaries as Fish and Waterfowl Habitat

Numerous coastal and offshore fish species spend at least part of their lives in estuaries. Although the number of commercially important "estuarine dependent" species is lower in New England than in other parts of the east coast, these habitats are important nursery areas to several species valued by humans, most notably populations of winter flounder. Pollution of some of the Bays' urban estuaries, such as Boston and Salem Harbors, has been associated with a high incidence of disease in this fish (Moore *et al.*, 1985).

Anadromous fish are those that migrate inland from marine habitats to spawn. In the Massachusetts Bays region, these include alewives, blueback herring, American shad, rainbow smelt, Atlantic salmon, and Atlantic and short-nosed sturgeon (Reback and Dicarlo, 1972; Chase, 1994). Over the years, these fish have suffered greatly from habitat degradation, particularly in the coastal rivers that are their spawning sites (Chase, 1994). The state's smelt fisheries, in particular, have declined sharply in recent years. Presently, Boston Harbor is one of the few regions where a viable smelt fishery still exists. (The top three rivers for smelt production in the Bays region are the Neponset River, Back River, and Fore River). Much of the decline in their populations can be attributed to the restricted access to these spawning sites caused by dams and other physical impediments. In addition, key spawning sites have been destroyed by siltation, excessive growth of algae, and other forms of pollution. The success of present anadromous fish runs requires a vigilant and effective stream management effort.

Large wintering populations of sea ducks, gulls, and alcids (penguin-like sea birds) use a variety of estuarine and nearshore habitats. In addition, gulls, terns, cormorants, herons, and egrets summer in the Bays region and depend on a number of offshore islands for nesting. The greatest threat to these birds is habitat degradation, both here in Massachusetts and in areas where they spend the rest of their migratory lives (Buchsbaum, 1992).

The Human Habitat

In 1992, a major socio-economic analysis of the Bays' resources (Bowen *et al.*, 1992) paved the way for CCMP priority setting.

Population Pressure

People are the ultimate source of most of the water quality problems and habitat degradation in Massachusetts and Cape Cod Bays. The coast of Massachusetts Bay is among the most densely populated of any estuary in the National Estuary Program (NOAA, 1990), and the population is expected to grow. Population projections for the United States as a whole indicate that there is a national trend toward living in the coastal zone. Two Massachusetts Bays counties in which significant future population growth is projected are Middlesex and Barnstable Counties. The primary environmental issue associated with population growth is new development that triggers increases in sewage effluent, stormwater runoff, and other nonpoint sources of pollution.

Shipping, Boating, and Dredging

Boston is the major shipping port in the Massachusetts Bays region, generating $1.858 billion in economic activity, based on 1992 figures from the Massport Authority (Massport, 1995). The recreational boating industry in Massachusetts employs nearly 9,000 workers who receive a total payroll of $187 million (Cavanaugh and Lewis, 1990). To maintain this shipping and boating activity, Boston and other harbors require periodic dredging. A major and ongoing management issue is the disposal of dredged materials, especially those that are contaminated. At present, there is no entirely satisfactory solution. Other management issues associated with maritime activity are chronic oil spills and bacterial pollution from marine sanitation devices.

Tourism

Tourists in Massachusetts coastal regions spend about $1.5 billion per year and support nearly 81,000 jobs. A major management issue associated with tourism is the conflicts that arise between recreational use and the protection of critical coastal resources, especially those on barrier beaches.

Whalewatching is one of the Bays' most popular tourist pastimes. About 1.25 million passengers per year visit Stellwagen Bank and Jefferies Ledge to view these spectacular cetaceans. Guidelines have been issued by the National Marine Fisheries Service (NMFS) to address concerns about the potential inadvertent harassment of whales by observation boats approaching too closely.

Cultural Resources

The Bays region has a long and rich cultural history, beginning with the first Native American inhabitants of approximately 12,000 years ago (when the continental shelf was exposed as a broad coastal plain) and continuing into the present. A recent survey of data at the Massachusetts Historical Commission (MHC) indicates that the coastal region has the highest density of ancient archaeological sites in the state. Marine resources have been a significant part of Native American subsistence strategies for millennia. European explorers were initially attracted to the Bays for their fishing potential in the 15th century and much of the early colonial settlement was oriented here. Key aspects of the Commonwealth's history are related to its sea-faring industries and dependence on the maritime trades and economies. Important historic and archaeological resources include shipwrecks, marine-dependent structures (e.g., wharves and lighthouses), and various archaeological sites. The latter include Native American habitation areas and villages, historical colonial settlements, and historical marine industries (ships, shipyards, saltworks, fish flakes). Together, these rich cultural resources help define the unique character of the Bays region and provide a better understanding of its historical use and development.

Fishing

Fishing has been an economic and cultural staple of coastal Massachusetts since Colonial times. According to a recent MBP-funded study (Bowen *et al.*, 1992) the total value of fish and shellfish landed in Massachusetts and Cape Cod Bays in 1990 was about $53 million. Lobsters accounted for about 60 percent and finfish 33 percent of this amount. Bluefin tuna brought in the greatest landed value among the finfish, followed by cod, winter flounder, yellowtail flounder, Atlantic herring, and spiny dogfish. Shellfish other than lobsters (primarily soft-shelled clams, quahogs, and sea scallops) accounted for 6.5 percent of the total landed value.

Recreational and sport fishing are also significant to the region's economy. In 1989, 634,000 recreational fishermen harvested $12 million worth of fish from the Massachusetts Bays. Bowen *et al.* (1992) estimated that the annual economic benefit of recreational fishing in the Massachusetts Bays is between $45 and $355 million, equaling or exceeding that of commercial fishing.

It is widely known that major commercial species of Massachusetts Bays are overfished in the region, an ecological tragedy that has led to severe economic hardship for traditional fishing-dependent communities, such as Gloucester (Correia, 1992; Buchsbaum *et al.*, in progress). Eight out of eighteen species of finfish that occur in the Massachusetts Bays region were listed as overexploited by the Northeast Fisheries Science Center of NMFS in their 1993 survey. Total landings of the three most important species of groundfish in Massachusetts waters -- cod, winter flounder, and yellowtail flounder -- are now roughly only 15 percent of what they were in the late 1970s (EOEA, 1990). Haddock, a species long prized by fishermen and consumers, has all but disappeared from Massachusetts waters. Ocean scallops and lobsters in the Gulf of Maine are also classified as overexploited.

In response to these distressing trends, NMFS recently issued new regulations designed to drastically cut fishing mortality by limiting the areas open to fishing, the length of time fishermen can fish, and the total number of people who can fish. At the same time, the Massachusetts Division of Marine Fisheries (DMF) has placed limits on the size of boats that can fish in state waters. Despite these actions, however, recovery of the stocks is uncertain. Atlantic herring is one of the few species that have made a successful comeback from an overfished condition.

Although overfishing is generally considered to be the primary cause of the current crisis in the fishing industry, pollution and habitat loss are thought to play a role as well, especially among fish that spawn nearshore or are anadromous. Such fish have much greater exposure to polluted water and sediments than offshore species. Entrainment of fish in power plant intakes may account for some additional localized impacts. In the spring of 1996, MBP hosted a workshop to present the results of a MBP-funded analysis of the factors impacting fish populations (Buchsbaum, *et al.*, in progress).

Toxic Contamination of Massachusetts Bays Habitats and Resources

Pollutants in Massachusetts and Cape Cod Bays, such as nitrogen, suspended solids, polycyclic aromatic hydrocarbons (PAHs), chlorinated hydrocarbons, trace metals, and pathogens, can increase risks to human health, habitats, and sustainable resources. These pollutants enter the Bays in either one of two general modes: from point sources (i.e., direct discharges) or from nonpoint sources (i.e., diffuse sources such as stormwater, groundwater, or the atmosphere).

Sources of Pollutants to Massachusetts Bays

Recent studies indicate that the drainage basins for Boston Harbor, the lower North Shore, and the Merrimack River contribute the largest pollutant loads to the Bays. Major sources within these basins are effluent from municipal wastewater treatment facilities and industries, rivers, stormwater runoff, and atmospheric deposition (Menzie-Cura, 1991; Menzie-Cura, 1995 a,b; Golomb *et al.*, 1995).

Wastewater treatment facilities, particularly the large ones run by the MWRA, are among the greatest contributors of trace metals, especially copper, lead, and zinc (Alber and Chan, 1994; Uhler *et al.*, 1994; Menzie-Cura, 1995b). In recent years, the level of metals discharged by MWRA facilities has declined due to an industrial pretreatment program and a slower economy (Alber and Chan, 1994). Industrial pipes are generally not a large "direct" source of toxic pollutants to the Bays, as most industries discharge their wastewater into municipal sewer systems rather than directly into the Bays or their tributaries.

The Merrimack River, which drains the largest watershed to the Bays, contributes an estimated 10-40 percent of the total copper load to Massachusetts Bay. It is also an important source of lead, chromium, and mercury. Many of these pollutants are discharged to the Merrimack River by municipal wastewater treatment facilities and industries in the urban centers along the river (Menzie-Cura, 1991). Rivers entering Boston Harbor are major sources of lead and PAHs (Menzie-Cura, 1991; Alber and Chan, 1994).

Stormwater is a significant cumulative source of pollutants on a Bays-wide scale and a major contributor to the degradation of many nearshore waters, including Boston Harbor. Combined sewer overflows (CSOs) also are a significant contributor of various pollutants to Boston Harbor. Atmospheric deposition is a significant contributor of nitrogen, organic compounds (PAHs and polychlorylbiphenyls, or PCBs), and certain trace metals (cadmium, lead, zinc, and mercury). These pollutants enter the atmosphere from car exhaust and emissions from power plants and municipal incinerators (Golomb *et al.*, 1996; Zemba, 1996).

Concentrations of Toxic Pollutants in the Water Column and Sediments

In general, the concentrations of toxic pollutants in the water column in Massachusetts Bays gradually decrease with distance from shore. In parts of Boston Inner Harbor, Salem Sound, and northern Massachusetts Bay, levels of trace metals exceed those recommended by EPA for chronic toxicity to marine life. In addition, contaminated sediments can be a steady source of some toxic pollutants to the water column.

The contaminant levels in virtually all sediments in the Bays are above background levels, even in relatively pristine Cape Cod Bay (Knebel *et al.*, 1991; Hyland and Costa, 1995; Shea and Seavey, in progress). To assess the impact of contaminated sediments on the community of marine invertebrates inhabiting the sediments, MBP funded a sediment triad analysis (Hyland and Costa, 1995). For a variety of coastal sites, this study compared sediment toxicity, contaminant concentrations, and the health of the benthic community. In most areas of the Bays, contaminant levels are below those thought to impact benthic organisms. Nevertheless, there are a number of toxic "hot spots" in depositional areas where toxic contaminants and high levels of organic matter accumulate, resulting in fewer benthic species (Hyland and Costa, 1995). Nearshore sediments in Boston Harbor, Salem Sound, and Broad Sound contain a long list of potentially toxic compounds at hazardous levels (Moore *et al.*, 1995; Hyland and Costa, 1995; NOAA, 1991). In Boston Harbor, levels of chromium, copper, zinc, lead, mercury, PCBs, and DDT significantly exceed the National Oceanic and Atmospheric Administration's (NOAA's) lowest effect range. Chromium is elevated in Salem Harbor sediments (MacDonald, 1991). The Massachusetts Bay Disposal Site and the future MWRA outfall site both violate EPA's proposed sediment criteria for certain PAHs (Cahill and Imbalzano, 1991). (However, with respect to the MBDS, it should be pointed out that the MBDS has not been found to have a significant adverse impact on the habitat of Massachusetts Bay, based on the findings of the MBDS Environmental Impact Statement (EIS) and Disposal Area Monitoring System (DAMOS) research. The Public Record of Decision for the Final EIS for the designation for the MBDS indicated that "The MBDS has been previously used without any significant adverse effects to the marine ecosystem or human health and the proposed future use of the modified MBDS should have no such effects either.")

To further our understanding of the nature of the sediment pollution in the Bays, MBP funded an analysis of pollution levels in cores taken from Massachusetts and Cape Cod Bays (Shea and Seavey, in progress). In addition, MBP funded a review of available sediment pollution data (Cahill and Imbalzano, 1991). These and related studies assist the MBP in understanding the potential impact of major dredging and dredged materials disposal projects in the Bays, as well as characterizing the results of long-term disposal of pollutants into the Bays' waters.

Levels of selected contaminants are expected to decrease in Boston and Salem Harbors as a result of ongoing improvements to wastewater treatment facilities, reduction in CSOs, and the reduced use of certain toxic pollutants, such as DDT, PCBs, and chromium. To help these and other communities implement CCMP actions related to controlling sediment pollution, the MBP funded an analysis of stormwater Best Management Practices and related costs in the Salem Sound area (Battelle, in progress).

Effects of Contaminants on Organisms in the Bays

Diseases and other physiological effects attributed to toxic pollutants have been found in fish and shellfish from Boston Harbor, Broad Sound, and Salem Harbor (Moore *et al.*, 1995; McDowell *et al.*, in progress). Diseases associated with PAHs (e.g., a precancerous condition of the liver) were much higher in winter flounder from Boston Harbor than in flounder from offshore sites (Sullivan and Robinson, 1990; Moore *et al.*, 1992; Moore and Stegeman, 1993). A study by DMF showed that tissue PCB concentrations are elevated in winter flounder and lobsters from Salem Sound and Boston Harbor compared to those from non-urban coastal sites (Schwartz *et al.*, 1991). The effect of toxic pollutants on important marine organisms at the population level is currently being investigated (McDowell, in progress).

To clarify the role of food chain transfer in PAH uptake, the MBP funded a study of PAH metabolism in clams and marine worms (McElroy *et al.*, 1994). In addition, a MBP study examined a biochemical marker that is induced in populations of fish and intertidal shellfish from the Bays which have been exposed to organic contamination. The marker has the potential to serve as monitoring tool to assess pollution exposure (Moore *et al.*, 1995). These studies and related research will be useful in tracking the recovery of the Bays as the CCMP is implemented.

The risk to humans of consuming fish and shellfish containing toxic pollutants is assessed by comparing contaminant levels in edible tissues with action levels set by the federal Food and Drug Administration (FDA). In general, fish in the Massachusetts Bays are considered safe to eat by current standards of risk analysis. The only current health advisory is for the consumption of lobster tomalley from lobsters caught anywhere in Massachusetts Bay and a limited advisory for sensitive people for lobster, flounder, and bivalves from Boston Harbor and bluefish from Massachusetts Bay (US EPA, 1988). An EPA study of fish and shellfish in Quincy Bay puts the risk of developing cancer as a result of consuming PCBs in winter flounder, clams, and lobsters (excluding tomalley) at between one in 1,000 to one in 100,000, depending on how regularly the fish or shellfish is consumed (US EPA, 1998). The consumption of lobster tomalley alone posed the highest risk, one in 100.

Most fish advisories in Massachusetts are restricted to rivers and lakes. Health risks associated with consumption of fish from our marine waters, even those of Boston Harbor, are low. Nonetheless, there are *some* risks, though fish in the Bay are generally considered safe to eat.

Pathogen Contamination of Sustainable Resources

Shellfish Bed Contamination

The closure of shellfish beds due to pathogen contamination is, in the eyes of the public, one of the major environmental and economic problems facing Massachusetts and Cape Cod Bays. Indeed, the 80,000 closed acres of shellfish beds represent a significant annual economic loss to the state. A 1991 estimate of the economic loss from closed beds in the Ipswich River alone was $500,000 (Ipswich Shellfish Advisory Board, 1991). Coastwide, the annual losses are many times this amount.

Contaminated shellfish beds are closed to reduce risks to public health from pathogens in sewage. The two most frequent diseases attributed to sewage pollution of marine waters are gastroenteritis (caused by the Norwalk virus) and hepatitis A. Between 1961 and 1984, 6,000 and 1,400 cases of these two diseases, respectively, were reported in the United States (Williams and Fout, 1992). Many cases go unreported. Massachusetts has shown a promising trend of no reported cases over the past few years.

Although fecal coliform bacteria generally do not cause diseases themselves, they are used as an indicator of the presence of pathogens. Shellfish beds are open to harvesting when overlying waters are less than a (geometric) mean of 14 fecal coliform bacteria per 100 milliliters (ml) of water for 15 samples. No more than 10 percent of those 15 samples can exceed 43 fecal coliforms per 100 ml. (See U.S. Department of Health and Human Services, Food and Drug Administration's 1989 Revision of the *National Shellfish Sanitation Program's (NSSP) Manual of Operations, Part I, Sanitation of Shellfish Growing Areas.*) Many shellfish areas in Massachusetts are conditionally approved, meaning that they are open except during certain predictable pollution events, such as rainstorms or sewage overflows. These areas may be closed during certain seasons or classified as restricted, in which case the shellfish can be harvested but must "cleaned" at a relay site or depuration facility for several days prior to marketing. Beds may be classified as "prohibited" due to high levels of fecal coliforms or subjected to management closure because they were not surveyed. DMF has responsibility for monitoring and classifying all shellfish harvesting areas in the Commonwealth.

At the time of this writing, 61 percent, or 252,568 out of 413,341 acres of Massachusetts Bays coastal waters, are classified as permanently open to shellfishing. As mentioned above, 80,000 acres of the total closed acreage is considered productive (i.e., contains harvestable shellfish). On a regional basis, only 36 percent of the coastal waters from New Hampshire through Boston Harbor are open, compared with 81 percent on the South Shore and 90 percent on Cape Cod (DMF statistics).

Over the past twenty-five years, the acreage of coastal waters open to shellfishing has gradually declined (Buchsbaum, 1992; Heufelder, 1988; Leonard *et al.*, 1989). Between 1970 and 1990, the closed acreage roughly tripled on the South Shore and increased about twenty-fold on Cape Cod. On a more positive note, however, several shellfish beds in the region have been reopened since 1991.

Studies in a number of areas around Massachusetts and Cape Cod Bays (Ipswich, the Annisquam River, Salem Sound, the North River-Scituate, and Cape Cod) show that the primary causes of closures of shellfish beds are inadequate sewage treatment systems, illegal sewer tie-ins to storm drains, stormwater runoff, and wastes from livestock, pets, and wild animals (Roach, 1992; Cooper and Buchsbaum, 1994; Heufelder, 1988). Most of the recent large increases in closures of shellfish growing waters in Massachusetts are attributed to increased development along the coast, resulting in increased nonpoint source pollution, and more intensive monitoring. Nonpoint source pollution of shellfish beds, particularly from stormwater, is often technically difficult to mitigate, since it requires the tracking of many small and diffuse sources, each of which may be polluting only intermittently. Creative land use planning and innovative engineering solutions are required to alleviate this problem and prevent future degradation. MBP is developing a model to help communities identify shellfish beds at risk of closure from future development (Horsley-Witten, in progress).

[Note: While most shellfish bed closures are due to pathogen contamination, certain biotoxins such as paralytic shellfish poisoning (PSP) periodically play a role in bed closures as well. PSP is a naturally-occurring seafood toxin that is caused by a tiny microorganism known as a dinoflagellate, *Alexandrium tamarense*. When the PSP-causing organism is present in large numbers, it is often referred to as "red tide." PSP can lead to serious health effects, and there is no known antidote. Shellfish that are harvested as part of a recreational or subsistence fishery appear to pose the greatest health risk because individuals may not be aware of a problem or do not heed the warnings.

Data from the Centers for Disease Control (CDC) indicated that between 1978 and 1985, there were 15 reported cases of PSP in Massachusetts. While the Northeast Technical Services Unit (NETSU) of the US food and Drug Administration (FDA) reported 41 cases in the same period, milder cases may actually go unreported to health authorities. The incidence of PSP is relatively low considering that the dinoflagellate has been present in Massachusetts coastal waters each spring and summer since monitoring began in 1972. Nevertheless, the PSP problem has been spreading down the coast of the Gulf of Maine for years, with red tide events now occurring periodically in Cape Cod Bay.

Coastal waters as well as the marketplace are monitored for indications of PSP by the Massachusetts Division of Marine Fisheries (DMF) and the Massachusetts Department of Public Health (DPH), respectively. This monitoring system appears to provide adequate public health protection.]

Closures of Swimming Beaches

Beaches are closed to swimming if fecal coliform counts exceed 200 cells per 100 ml seawater. Gastroenteritis is the most common disease that is contracted by swimming in contaminated waters. The Massachusetts Bays Program has calculated that about 10,000 swimmers annually may suffer illness as a result of incidental ingestion of marine waters. This translates to an annual risk of about one in a hundred. The beaches posing the greatest risks are primarily in the region extending from Boston Harbor through Salem. These same beaches experience the greatest number of pollution-related closures.

A positive trend is the decrease in beach closures in Boston Harbor over the past few years. This has been attributed to chlorination of CSOs, repair of sewage interceptor conduits, and cessation of sludge discharges to the Harbor (Rex *et al.*, 1992).

Massachusetts Water Quality Standards

The Massachusetts Division of Water Pollution Control (DWPC), a division within the state Department of Environmental Protection (DEP), sets water quality standards and designated uses for specific coastal and inland waters. These are goals, and are based on an assessment of what a particular body of water should be able to achieve, both in terms of water quality and for shellfishing, fishing, swimming, and sustenance of aquatic life. Coastal waters are classified as either "SA," waters with the highest expected uses, or "SB," areas which cannot meet SA standards. The DWPC, through its biennial water quality assessment reports (under §305(b) of the Clean Water Act) to EPA, periodically assesses how well water bodies are achieving their targeted goals and designated uses.

About 60 percent of Massachusetts marine and estuarine waters assessed by the DWPC do not support their designated uses due to pollution. Another 30 percent support their uses and 10 percent are in partial compliance. Designated uses, such as shellfish harvesting, were achieved for only 58 percent of the waters classified as SA, and for only one percent of those classified as SB. The parameter most frequently causing non-attainment is fecal coliform bacteria. Stormwater, CSOs, and municipal point source discharges are the major sources of non-attainment. Toxic contaminants and organic enrichment often prevent waterbodies from achieving their designated uses for maintenance of aquatic life and fishing. These observations provide strong support for the MBP's priority goals of reducing pathogen contamination of shellfish beds and reducing toxic pollution from stormwater runoff. MBP-funded studies which have contributed to our understanding of the sources and loadings of pollutants entering the Bays include Menzie-Cura (1991), Menzie-Cura (1995a and 1995b), Golomb *et al.* (1995), and Zemba (1995).

Conclusion

Characterizing the status of the physical and biological resources of the Bays, as well as the sources, loadings, fate and effects of pollutants, serves as an essential first step in developing a sound comprehensive management plan. The recommendations in this CCMP have evolved from our understanding of the state of the Bays, coupled with the practical wisdom and experience of concerned citizens and agency professionals working together over the past five years.

[An expanded State of the Bays report is in preparation and will serve as a companion document to the CCMP.]